Executive Summary

Safe, breathable air is essential for crew health. Human space flight has involved toxicological events ranging in severity from trivial to life-threatening.

Toxic exposure to chemical contaminants can originate from system leaks, payload leaks, pyrolysis of polymeric materials, off-gassing of polymeric materials, use of utility compounds, propellant entry, microbial products, and human metabolism.

To ensure crew safety, NASA has developed a set of space flight specific air quality guidelines called Spacecraft Maximum Allowable Concentrations (SMACs) to define levels to which air pollutants must be controlled to ensure no adverse effects. Furthermore, the system shall include the ability to control/prevent contamination, monitor contaminants, provide crew with appropriate Personal Protective Equipment (PPE) and mitigate contamination, including cleaning affected surfaces and treating crewmembers, should an event occur.

Relevant Standards

NASA-STD-3001 Volume 1, Rev B
[V1 3003] In-Mission Preventative Health Care
[V1 3004] In-Mission Medical Care

NASA-STD-3001 Volume 2, Rev C
[V2 3006] Human-Centered Task Analysis
[V2 4015] Aerobic Capacity
[V2 5004] Cognitive Capabilities
[V2 6001] Trend Analysis of Environmental Data
[V2 6002] Inert Diluent Gas
[V2 6004] Nominal vehicle/Habitat Carbon Dioxide Levels
[V2 6022] Atmospheric Monitoring and Alerting Parameters
[V2 6023] Trace Constituent Monitoring and Alerting
[V2 6024] Combustion Monitoring and Alerting
[V2 6025] Contamination Monitoring and Alerting
[V2 6047] Toxic Hazard Level Three
[V2 6048] Toxic Hazard Level Four
[V2 6049] Chemical Decomposition
[V2 6050] Atmosphere Contamination Limit
[V2 6052] Particulate Matter
[V2 6053] Lunar Dust Contamination
[V2 6062] Availability of Environmental Hazards Information
[V2 6063] Contamination Cleanup
[V2 6109] Water Quantity
[V2 6153] Celestial Dust Monitoring
[V2 7043] Medical Capability
[V2 7069] Labeling of Hazardous Waste
[V2 7080] Particulate Control
[V2 7082] Surface Material Cleaning
[V2 8001] Volume Allocation
[V2 9024] Fluid/Gas Release
[V2 9025] Fluid/Gas Isolation
[V2 9026] Fluid/Gas Containment
[V2 9053] Protective Equipment
[V2 9054] Protective Equipment Use
[V2 11001] Suited Donning and Doffing

Bill McArthur (Exp. 12) with the Volatile Organic Analyzer on ISS

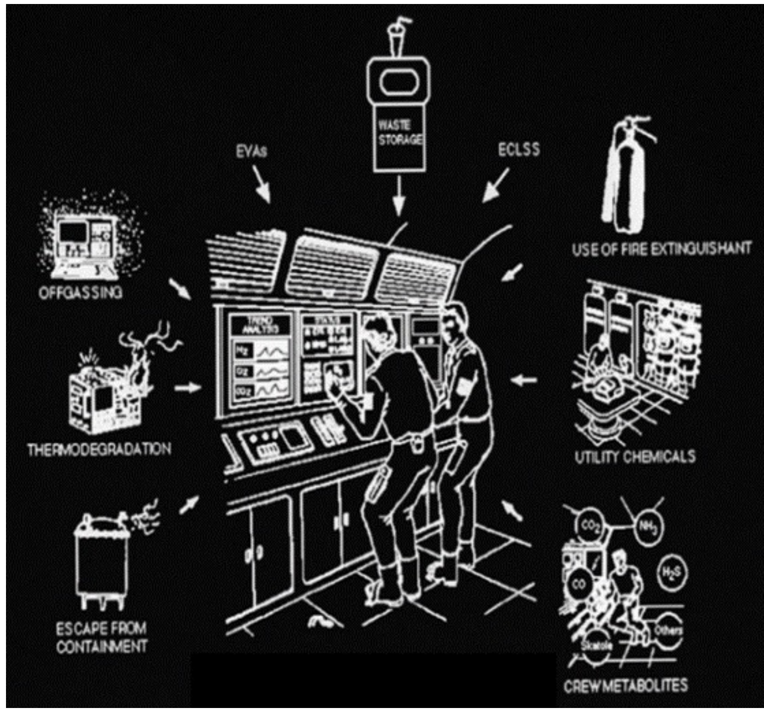
Background

Sources of Toxic Chemicals in Spacecrafts

- Compounds used in systems (e.g., ammonia, ethylene glycol, Freon 218)
- Payload chemicals (e.g., fixatives)
- Off-gassed products (e.g., formaldehyde)
- Batteries (electrolytes and fire hazard)
- Products of corrosion
- External contaminants (e.g., Fuel Oxidizer Reaction Product (FORP))
- Operational anomalies/hardware failures & repair (e.g., SKV Heater)
- Thermal degradation of electronic components and other fires

- The threat to crew health may occur as a result of inhalation, ingestion, or dermal/ocular contact with the contaminants.
- Contact exposure to chemicals can cause injury to the skin and eyes; inhalation can damage the lungs; ingestion can damage the digestive tract; and any method of exposure can have a systemic effect that could be hazardous depending on the chemical and amount.
- The effects of exposure to toxic hazards can vary in type and severity.
- The JSC toxicologists establish guidelines for safe and acceptable levels of individual chemical contaminants in spacecraft air (SMACs) to provide guidance on allowable chemical exposures during nominal operations and emergency situations.

Common sources of air contaminants



Toxicological Hazard Levels

Hazard Level	Irritancy	Systemic Effects	Containability
0	Slight-lasts <30 min-no therapy	None	+/-
1	Slight to moderate-lasts >30 min-therapy	Minimal effects-no potential for long-term effects	+/- Surgical masks, gloves, goggles
2	Moderate to severe-possible long-term effects	Minimal effects-no potential for long-term effects	+ Surgical masks, gloves, goggles
3	Moderate to severe-possible long-term effects	Appreciable effects-potential for long-term effects	+ Quick-don masks and gloves
4	Moderate to severe-possible long-term effects	Appreciable effects-potential for long-term effects	- Quick-don masks and ARS or evacuation

Background

Exposure Guidelines (SMACs)

SMACs are set to protect healthy crewmembers from adverse effects, significant discomfort, or degradation in performance resulting from continuous exposure to airborne substances (such as gas, vapor, or aerosol).

Length of Exposure	Exposure Guidelines (SMACs)
1 and 24 hours	Guidelines intended to allow performance of specific tasks during emergency conditions lasting up to 24hr. Exposure to 1-or 24-hr SMACs will not cause serious or permanent effects but may cause reversible effects that do not impair judgment or interfere with proper responses to emergencies such as fires or accidental releases. Short-term SMACs are intended for off-nominal events and should not be used for system design or evaluation of routine exposures.
7, 30, and 180 days	Guidelines intended to avoid adverse health effects (either immediate or delayed) and to avoid degradation in crew performance with continuous exposure in a closed environment for various durations.
1000+ days	Guidelines intended for longer space missions beyond low Earth orbit and to other celestial bodies.

Guidelines for Developing SMACs

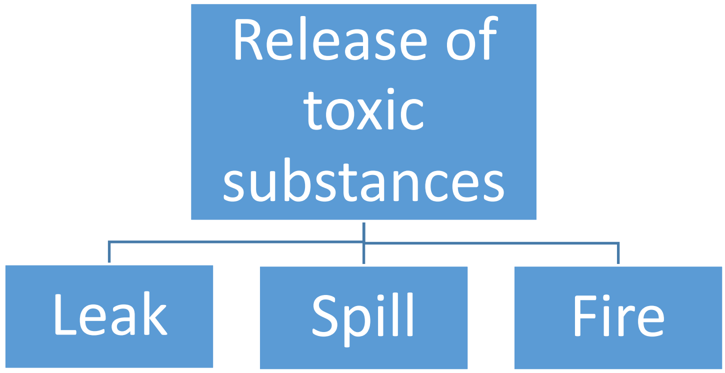
When developing appropriate exposure criteria, experts take into account:

- Microgravity environment: Deposition of particles, lung function, and the toxic potential of inhaled particles may be different under microgravity conditions than under full gravity conditions, as on Earth.
- Radiation:
  - Due to the potential interaction of radiation and benzene leading to leukemia (Khan-Mayberry, 2008) and the relatively high radiation environment of space, SMACs for benzene are set at lower levels of acceptable exposure.
- Astronauts' physical, physiological, and psychological conditions:
  - Loss of muscle and bone mass
  - Altered immune system
  - Cardiovascular changes
  - Decreased red blood cell mass
  - Altered nutritional requirements
  - Behavioral changes from stress
  - Fluid shift in the body
  - Altered hormonal status
  - Altered drug metabolism


Carbon Dioxide Removal Assembly (CDRA) on ISS

Reference Data

Spacecraft-Atmosphere Contamination Sources



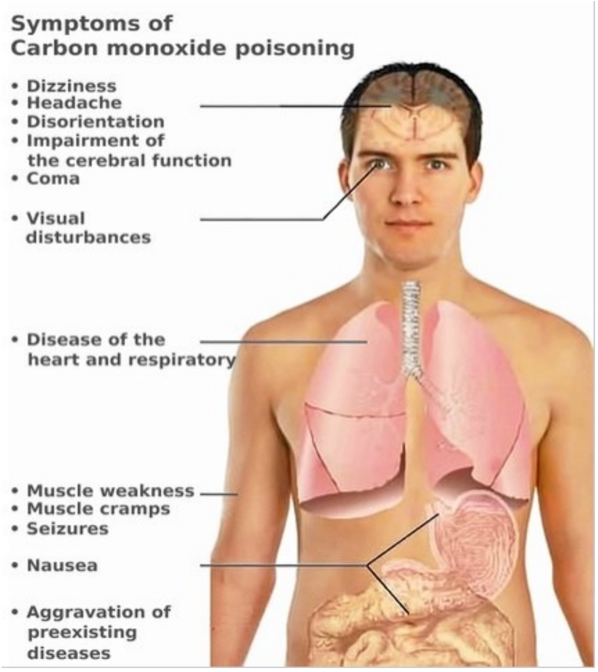
Carbon Dioxide (CO_2)

- **What is it**: CO_2 is a product of respiration. Concentrations increase in confined areas, especially if they are poorly ventilated.
- **Sources:** Human and animal payload metabolism/expiration, increased production during exercise.
- **How does it affect crew health:** Overexposure to CO_2 can cause headaches of varying severity, vision changes, nausea, and unconsciousness in severe overexposure.

See also: NASA OCHMO CO_2 Technical Brief

Carbon Monoxide (CO)

- **What is it**: CO is an odorless, colorless gas that is produced by incomplete combustion of carbon-containing materials (Penny 2000a).
- **Sources**: In spaceflight, CO production will most likely be associated with a fire.
- **How does it affect crew health:** The most common symptoms of CO poisoning includes headache, dizziness, weakness, upset stomach, vomiting, chest pain, and confusion. These symptoms depend on a combination of the airborne concentration of CO, the activity level of the exposed individual, and the length of exposure.



CO Toxicity Symptoms

Reference Data

Freons and Other Halocarbons

- **What is it**: Halocarbons are mostly human-made gases consisting of both carbon and at least one of the halogens (fluorine, chlorine, iodine, and bromine).
- **Source:** Crewmembers could be exposed in the event of a leak.
- **How does it affect crew health:** This group of halocarbons has very low toxicity. The primary effect of this class of compounds is cardiac sensitization leading to rhythm disturbances. This effect is generally noted only at concentrations above 1%.

Ammonia

- **What is it:** Ammonia is a water-soluble gas with a characteristic pungent smell.
- **Source:** Ammonia accumulates slowly in spacecraft atmospheres as a result of human metabolism. It is also used in active thermal control of the U.S. Segment of the ISS and Orion. It can enter the cabin and expose the crew in a few ways:
  - Leaks in the cabin through the interface heat exchanger
  - Compromised structural integrity from a hard landing causing a leak in the cabin
  - Vented ammonia brought in by the snorkel fan
- **How does it affect crew health:** Inhalation of lower concentrations can cause coughing and nose and throat irritation. Exposure to high levels of ammonia in air causes immediate burning of the nose, throat, and respiratory tract which might lead to respiratory distress or failure.

Estimated toxic response to acute exposures to ammonia vapors

Ammonia concentration (ppm)	Degree of irritation
5	Odor threshold in sensitive persons
20–30	Some sense a slight irritation
50	Odor threshold in nonsensitive persons, perceptible to moderate irritation
80	Distinctively perceptible irritation
110	Irritation is a nuisance
140	Nuisance, offensive, and unbearable irritation
700	Immediate eye injury
1700	Laryngospasm
2500–3500	Death

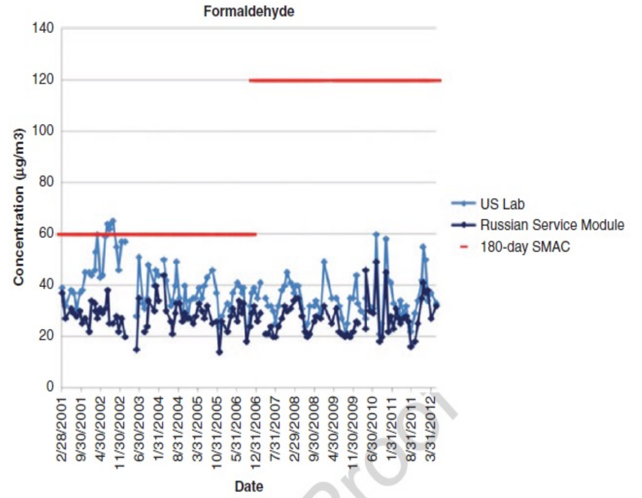
Ammonia mask fitted with ammonia cartridges

Reference Data

Formaldehyde

- **What is it**: Formaldehyde is a colorless gas with a pungent and suffocating smell.
- **Source**: It can enter space vehicles through leakage of fixatives from payload experiments, off-gassing of hardware, thermo-degradation of certain polymeric materials, and incomplete oxidation of contaminants in the environmental control system.
- **How does it affect crew health**: It is an irritant to the eyes and respiratory system, and after prolonged exposure, is carcinogenic.

Profile of formaldehyde in the U.S. Lab and Russian Service Module over the life of ISS



Airborne Carcinogens

- **What is it:** Volatile contaminants that may present an increased cancer risk with elevated exposure over time.
- **Source:** Most carcinogens originate from materials off-gassing. Common carcinogens monitored in spacecrafts and their primary sources are:
  - Acetaldehyde: Human metabolism, materials off-gassing
  - Benzene: Materials off-gassing, polymer pyrolysis
  - 1,2-dichloroethane: Hardware off-gassing
  - Formaldehyde: Hardware off-gassing
  - Furan: Hardware off-gassing, heating of organic materials
  - Isoprene: Human metabolism, plants
- **How does it affect crew health:** Acetaldehyde, benzene, and 1,2-dichloroethane have been shown to react with DNA and to cause mutations. Formaldehyde, furan, and isoprene cause cancer by epigenetic mechanisms. Most spaceflight exposures are not adequate in concentration or duration to present a significant increase in cancer risk to crew.

Noxious Compounds

- **What is it**: Malodorous compounds.
- **Source:** Noxious sulfur compounds can be produced by biological waste that is stored for long periods or as a by-product of human metabolism.
- **How does it affect crew health:** Noxious compounds may result in secondary health effects, such as nausea or headache, following exposure.

Reference Data

Airborne Particles and Dust

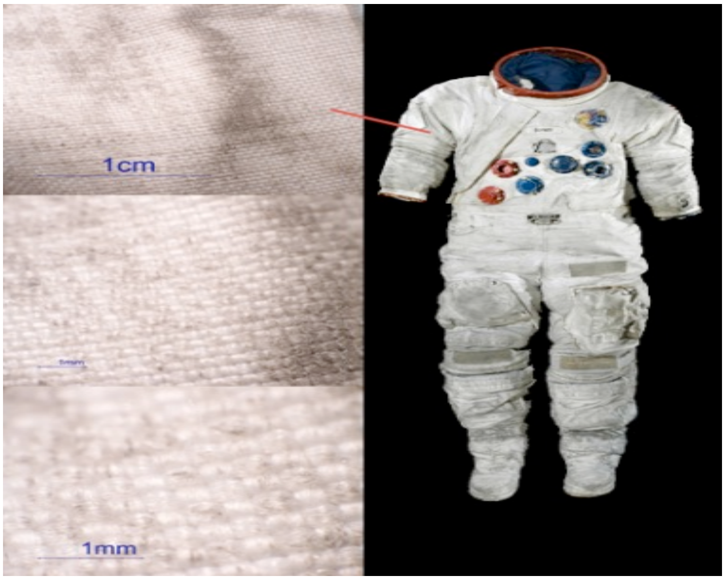
- **What is it:** Particles that are floating in the air.
- **Source:** Airborne particles could come from desquamation of skin cells from crewmembers, flaking of paint, release of lint from fabrics, and handling of food. Particles are also released from smoldering or fire events and are used for fire warning via smoke detection. Surface dust on celestial bodies, such as the Moon or Mars, may also contaminate spacecraft vehicles.
- **How does it affect crew health:** Microgravity will cause the particles to float, increasing the likelihood that they will enter the eyes and respiratory systems of crewmembers and cause irritation.
- **Relevant technical brief:** Lunar Dust.

Crewmember Shannon Walker using a vacuum during ISS routine housekeeping

Combined Exposures

- Spacecraft atmospheres are a complex mixture of various individual contaminants.
- To address exposure to multiple, rather than individual compounds, JSC Toxicology utilizes a hazard index or T-value. Air is deemed safe if the combined hazard index of all compounds with similar health endpoints is <1.

Apollo 17 astronaut Harrison Schmitt retrieves lunar samples during his December 1972 mission, his spacesuit dirtied by clinging lunar dust



Lunar dust

Reference Data

Examples of Toxicological Events During Spaceflight

Apollo 1 (1967): Fire on the pad at the Kennedy Space Center resulted in the death of 3 crewmembers in part due to toxic exposure to combustion products that were thought to include carbon monoxide, carbon dioxide, and irritant gases.

Apollo-Soyuz (1975): The Apollo capsule became highly polluted with nitrogen tetroxide during descent of the capsule through the atmosphere. The crew experienced respiratory symptoms and delayed release of fluid into the lungs. They were treated with oral steroids and released from the hospital 6 days post-landing.

STS-40 (1991): Motor from refrigerator/freezer produced formaldehyde during overheating. This irritating compound and others thought to be produced in the event seriously polluted the spacecraft atmosphere.

STS-55 (1993): The waste management system failed; therefore, waste was being stored in contingency waste bags. The crew reported a noxious odor emanating from the bags. An air sample analyzed later on the ground revealed that methyl sulfide compounds were being produced inside the bags.

Mir (1997): A solid fuel oxygen generator caught fire and burned in the cabin openly for at least a minute. Air samples revealed that dangerous combustion toxicants, such as carbon monoxide, remained at somewhat elevated but safe levels.

ISS/STS (1998): Toxic ammonia leak during EVA 1 on the mission. A defective quick-disconnect valve allowed 5% of the ammonia cooling supply to escape into space. The escaping ammonia froze on the spacesuit of an astronaut as he struggled to close the valve.

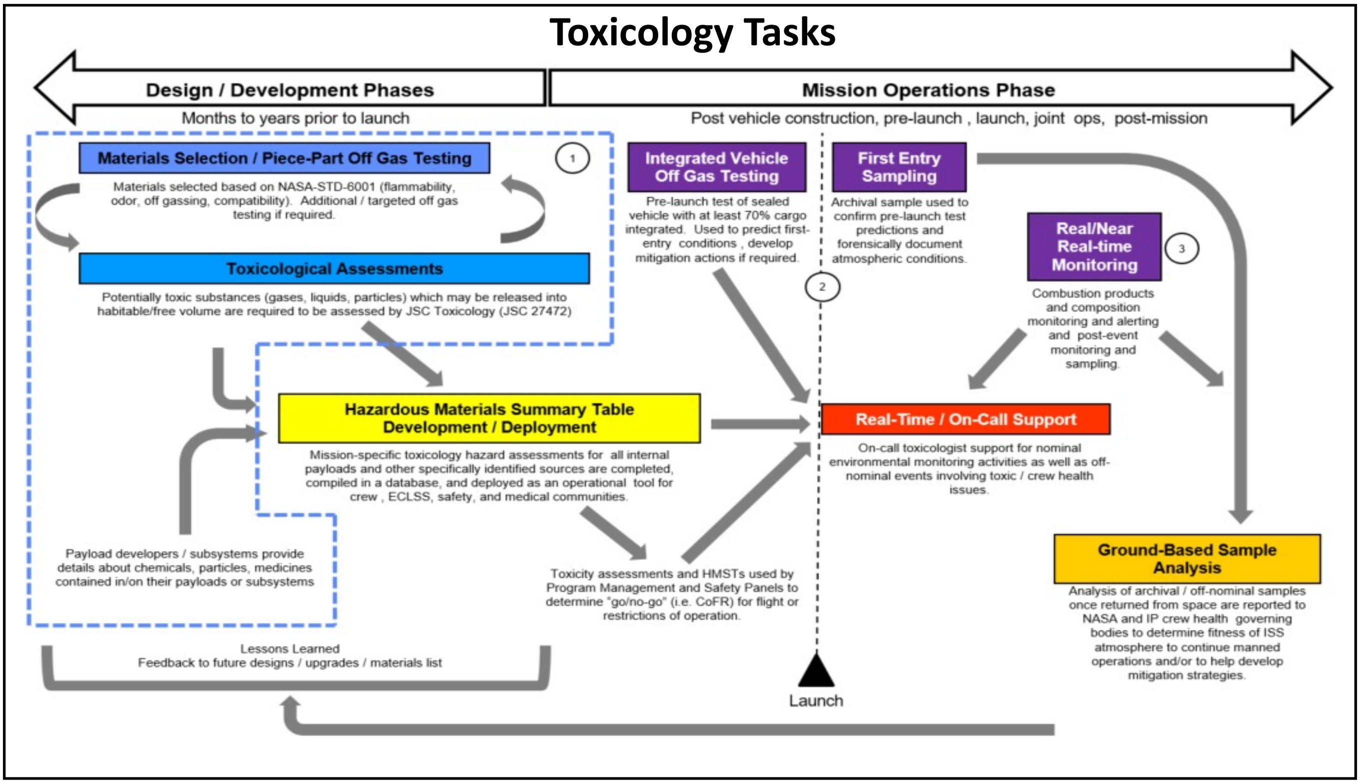
Normal Roentgenogram (left) and one from an Apollo astronaut accidentally exposed to propellants during capsule descent (right). The second figure suggests fluid infiltrate of the lungs.

Motor from STS-40 Orbiter Refrigerator/Freezer that produced formaldehyde during overheating.

Remains of the solid fuel oxygen generator that combusted aboard Mir space station in 1997.

Design Application

Spacecraft designs must control/prevent contamination, monitor contaminants, and mitigate contamination, including cleaning affected surfaces and treating crewmembers, should an event occur.



Implementation of Requirements/Standards

- NASA-STD-3001 requirements and SMACs need to be implemented in spacecraft development.

Materials Selection/Off-Gas Testing

- The habitable volume must contain chemicals that are **hazard level 3 or below.** Chemicals that are hazard level 4 must be prevented from entering the habitable volume. These levels depend on the inherent toxicity of the material, the amount of material that could be released into the atmosphere, the volume into which the release could occur, the nature of the injury (contact or systemic), and containability of a release.
  - Large volumes of relatively nontoxic material such as ammonia can be toxic hazard level 4, whereas small volumes of extremely hazardous materials such as thionyl chloride (found in some types of batteries) can also be toxic hazard level four.

Relevant NASA-STD-3001 Volume 2 Rev C Standards

[V2 6047] Toxic Hazard Level Three; [V2 6048] Toxic Hazard Level Four.

Design Application

Toxicological Assessments

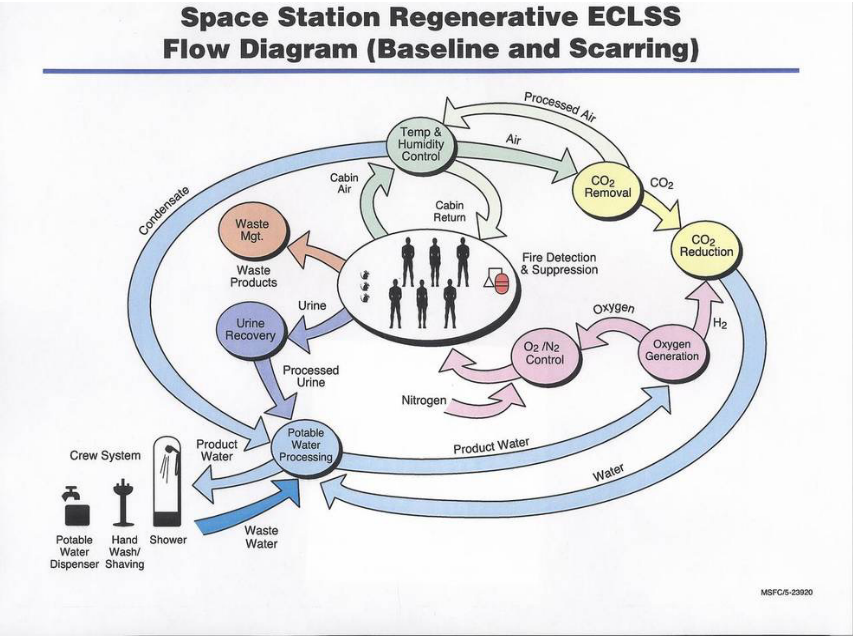
- Potentially toxic substances (gases, liquids, particles) that may be released into habitable/free volume must be assessed and provide appropriate mitigation and response strategies.
- All components and other materials to be carried on board must be tested to identify and quantify (under test conditions) off-gassing compounds.
- All hardware/payloads that include liquids, gases, particles, gels, or biological materials must contain a label so that the crew and ground personnel can easily identify whether the payload contains any toxic, biological, or flammability hazards.
- Crewmembers must be briefed prior to the flight so that they can identify toxic hazard labels and educate them on experiments and systems containing known toxic hazards. To quickly identify potential contaminants within the spacecraft, all toxicological and environmental hazard information (e.g., Material Safety Data Sheets [MSDS]) must be accessible to the crew throughout the mission.

Air Filtration

- A reliable environmental control and life-support system (ECLSS) must be provided to maintain the environmental parameters within standards.
  - ISS: The ISS ECLS system is designed to control temperature, humidity, and composition of space-station air, including CO_2 removal; water recovery; waste disposal; and detect and suppress fires.

Monitoring

- Monitoring and alerting are required to identify when hazardous contaminants are detected and to alert the crew so they can take appropriate actions to maintain health and safety.
- The type of monitoring that is needed and how often samples should be collected and analyzed depends greatly upon the mission length and vehicle architecture.



Design Application

Real-Time Air Monitoring

- Monitoring systems must provide real-time capability for the measurement and display of atmospheric concentrations of toxic combustion; as well as automatic alerts/alarms when levels are outside of the safe value range.

- Real-time monitors give the crew and ground personnel access to real-time chemical constituents in the air. Some are broad-spectrum, while others target specific components:
  - ✓ Compound specific analyzer for combustion products (CSA- CP)
  - ✓ Carbon monoxide monitor (CDM)
  - ✓ Air quality monitor (AQM)

Combustion product analyzer


Carbon Monoxide monitor


ISS personal CO_2 Monitor

Relevant NASA-STD-3001 Volume 2 Rev C Standards

- [V2 6022] The system **shall** alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO_2, and $ppCO_2$ are outside safe limits.

- [V2 6023] The system **shall** monitor trace volatile organic compounds (VOCs) in the cabin atmosphere and alert the crew locally and remotely when they are approaching defined limits.

- [V2 6024] The system **shall** monitor in real-time the toxic atmospheric components listed in Table 3, Recommended Combustion Product (CP) Monitoring Ranges, that would result from pre-combustion and combustion events in the ranges and with the accuracy and resolution specified in the table and alert the crew locally and remotely in sufficient time for them to take appropriate action.

- [V2 6025] The system **shall** monitor and display atmospheric compound levels that result from contamination events, e.g., toxic release, systems leaks, or externally originated, before, during, and after an event and alert the crew locally and remotely in sufficient time for them to take appropriate action.

Design Application

Archival Air Monitoring

- Archival air samples are collected using "grab sample containers" (GSC) and formaldehyde badges.

  Grab sample containers (GSC): Since the Gemini program, 3 archival air samplings have been performed on spacecraft as an element of crew health and safety to verify air quality and ECLSS performance forensically. Various types of grab sample containers have been used.

  Formaldehyde badges: Used for nominal sampling and can be used to detect formaldehyde in an area or adhered to a crewmember to detect personal exposures.

- Compound concentrations obtained by ground-based analyses of archival samples are compared with established requirements (SMACs) to assess the quality of the air during the mission. The processed data are then presented to the NASA toxicologist for a formal declaration on the air quality for the mission.

- For near-Earth mission lengths that extend to 6 months or more, air monitoring shifts to real-time monitors, with relatively few archival samples being collected and returned for later analysis.

- For missions beyond Earth orbit, the system needs to provide the necessary tools for onboard sample analysis.

Formaldehyde badge (FMK)

Personal Protective Equipment (PPE)

- Generic PPE for moderate toxin releases and specialized PPE for severe releases must be available to crew on the spacecraft.

Relevant NASA-STD-3001 Volume 2 Rev C Standards

- [V2 9053] Protective equipment **shall** be provided to protect the crew from expected hazards.

- [V2 9054] Protective equipment **shall** not interfere with the crew's ability to conduct the nominal or contingency operations that the crew is expected to perform while employing the protective equipment, including communication among crewmembers and with ground personnel.

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Referenced Standards

NASA-STD-3001 Volume 1 Revision B

[V1 3003] In-Mission Preventive Health Care All programs shall provide training, in-mission capabilities, and resources to monitor physiological and psychosocial well-being and enable delivery of in-mission preventive health care, based on epidemiological evidence-based probabilistic risk assessment (PRA) that takes into account the needs and limitations of each specific design reference mission (DRM), and parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. The term “in-mission” covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In-mission preventive care includes but is not limited to: (see NASA-STD-3001, Volume 1 Rev B for full standard).

[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, clinical practice guidelines and expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses should consider the needs and limitations of each specific DRM and vehicle. The term “in-mission” covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, are to include, but are not limited to: see NASA-STD-3001, Volume 1 Rev B for full standard).

NASA-STD-3001 Volume 2 Revision C

[V2 3006] Human-Centered Task Analysis Each human space flight program or project shall perform a human-centered task analysis to support systems and operations design.

[V2 4015] Aerobic Capacity The system shall be operable by crewmembers with the aerobic capacity as defined in NASA-STD-3001, Volume 1.

[V2 5004] Cognitive Capabilities The system shall accommodate anticipated levels of crew cognitive capabilities under expected tasks demands.

[V2 6001] Trend Analysis of Environmental Data The system shall provide environmental monitoring data in formats compatible with performing temporal trend analyses.

[V2 6002] Inert Diluent Gas For mission durations in excess of 2 weeks, the atmosphere shall contain a physiologically inert diluent gas to prevent lung collapse.

[V2 6004] Nominal vehicle/Habitat Carbon Dioxide Levels The system shall limit the average 1-hour CO2 partial pressure (ppCO2) in the habitat volume to no more than 3 mmHg (760 mmHg cabin pressure).

[V2 6022] Atmospheric Monitoring and Alerting Parameters The system shall alert the crew locally and remotely when atmospheric parameters, including atmospheric pressure, humidity, temperature, ppO_2, and $ppCO_2$ are outside safe limits.

[V2 6023] Trace Constituent Monitoring and Alerting The system shall monitor trace volatile organic compounds (VOCs) in the cabin atmosphere and alert the crew locally and remotely when they are approaching defined limits.

Referenced Standards

[V2 6024] Combustion Monitoring and Alerting The system shall monitor in real-time the toxic atmospheric components listed in Table 3, Recommended Combustion Product (CP) Monitoring Ranges, that would result from pre-combustion and combustion events in the ranges and with the accuracy and resolution specified in the table, and alert the crew locally and remotely in sufficient time for them to take appropriate action.

[V2 6025] Contamination Monitoring and Alerting The system shall monitor and display atmospheric compound levels that result from contamination events, e.g., toxic release, systems leaks, or externally originated, before, during, and after an event and alert the crew in sufficient time for them to take appropriate action.

[V2 6047] Toxic Hazard Level Three [The system shall use only chemicals that are Toxic Hazard Level Three or below, as defined in JSC-26895, Guidelines for Assessing the Toxic Hazard of Spacecraft Chemicals and Test Materials, in the habitable volume of the spacecraft.

[V2 6048] Toxic Hazard Level Four The system shall prevent Toxic Hazard Level Four chemicals, as defined in JSC-26895, from entering the habitable volume of the spacecraft.

[V2 6049] Chemical Decomposition The system shall use only chemicals that, if released into the habitable volume, do not decompose into hazardous compounds that would threaten health during any phase of operations.

[V2 6050] Atmosphere Contamination Limit The system shall limit airborne contaminants to concentrations specified in JSC-20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants.

[V2 6052]] Particulate Matter The system shall limit the cabin particulate matter concentration for total dust to <3 mg/m3, and the respirable fraction of the total dust to <2.5 µm in aerodynamic diameter to <1 mg/m3.

[V2 6053] Lunar Dust Contamination The system shall limit the levels of lunar dust particles less than 10 µm in size in the habitable atmosphere below a time-weighted average of 0.3 mg/m3 during intermittent daily exposure periods that may persist up to 6 months in duration.

[V2 6062] Availability of Environmental Hazards Information The system shall provide toxicological and environmental hazard information in formats accessible by the crew throughout the mission

[V2 6063] Contamination Cleanup The system shall provide a means to remove or isolate released chemical and biological contaminants and to return the environment to a safe condition.

[V2 6109] Water Quantity The system shall provide a minimum water quantity as specified in Table 4, Water Quantities and Temperatures, for the expected needs of each mission, which should be considered mutually independent**.**

[V2 6153] Celestial Dust Monitoring and Alerting The vehicle shall monitor celestial dust and alert the crew locally and remotely when they are approaching defined limits.

[V2 7043] Medical Capability A medical system shall be provided to the crew to meet the medical requirements of NASA-STD-3001, Volume 1.

Referenced Standards

[V2 7069] Labeling of Hazardous Waste Hazardous waste shall be labeled on the outermost containment barrier, and available as viewed from different sides of the container that the crew may regard it, to identify the hazard type and level contained (in accordance with JSC-26895).
[V2 7080] Particulate Control The system shall be designed for access, inspection, and removal of particulates that can be present before launch or that can result from mission operations.
[V2 7082] Surface Material Cleaning The system shall contain surface materials that can be easily cleaned and sanitized using planned cleaning methods.
[V2 8001] Volume Allocation The system shall provide the defined habitable volume and layout to physically accommodate crew operations and living.
[V2 9024] Fluid/Gas Release Hardware and equipment shall not release stored fluids or gases in a manner that causes injury to the crew.
[V2 9025] Fluid/Gas Isolation The system shall provide for the isolation or shutoff of fluids and gases in hardware and equipment.
[V2 9026] Fluid/Gas Containment The system shall provide for containment and disposition of fluids and gases that might be released.
[V2 9053] Protective Equipment Protective equipment shall be provided to protect the crew from expected hazards.
[V2 9054] Protective Equipment Use Protective equipment shall not interfere with the crew's ability to conduct the nominal or contingency operations that the crew is expected to perform while employing the protective equipment, including communication among crewmembers and with ground personnel.
[V2 11001] Suited Donning and Doffing The system shall accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations.

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